Coupled Mesoscale Modeling of the Atmosphere and Ocean

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Naval Research Laboratory

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Outline

Coupled Mesoscale Modeling of the Atmosphere and Ocean

- **Objective**
- **Approach**
- **COAMPS™ Description**
- **Project Tasks and Results:**
  - Atmospheric Reanalyses
  - Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea
  - Ocean Data Assimilation
  - Temporal Variations of the Ocean Mixed-Layer in the Mediterranean
- **Summary**

COAMPS™: Coupled Ocean/Atmosphere Mesoscale Prediction System; Registered Trademark of the Naval Research Laboratory

Objective

Coupled Mesoscale Modeling of the Atmosphere and Ocean

- **Build a Mesoscale Coupled Atmosphere-Ocean Data Assimilation System**
- **Study Methodology for Coupling** (e.g., one-way, two-way, frequency, resolutions)
- **Measure Effects of Coupling on Atmosphere and Ocean Forecasts**
- **Transition System to Operations**

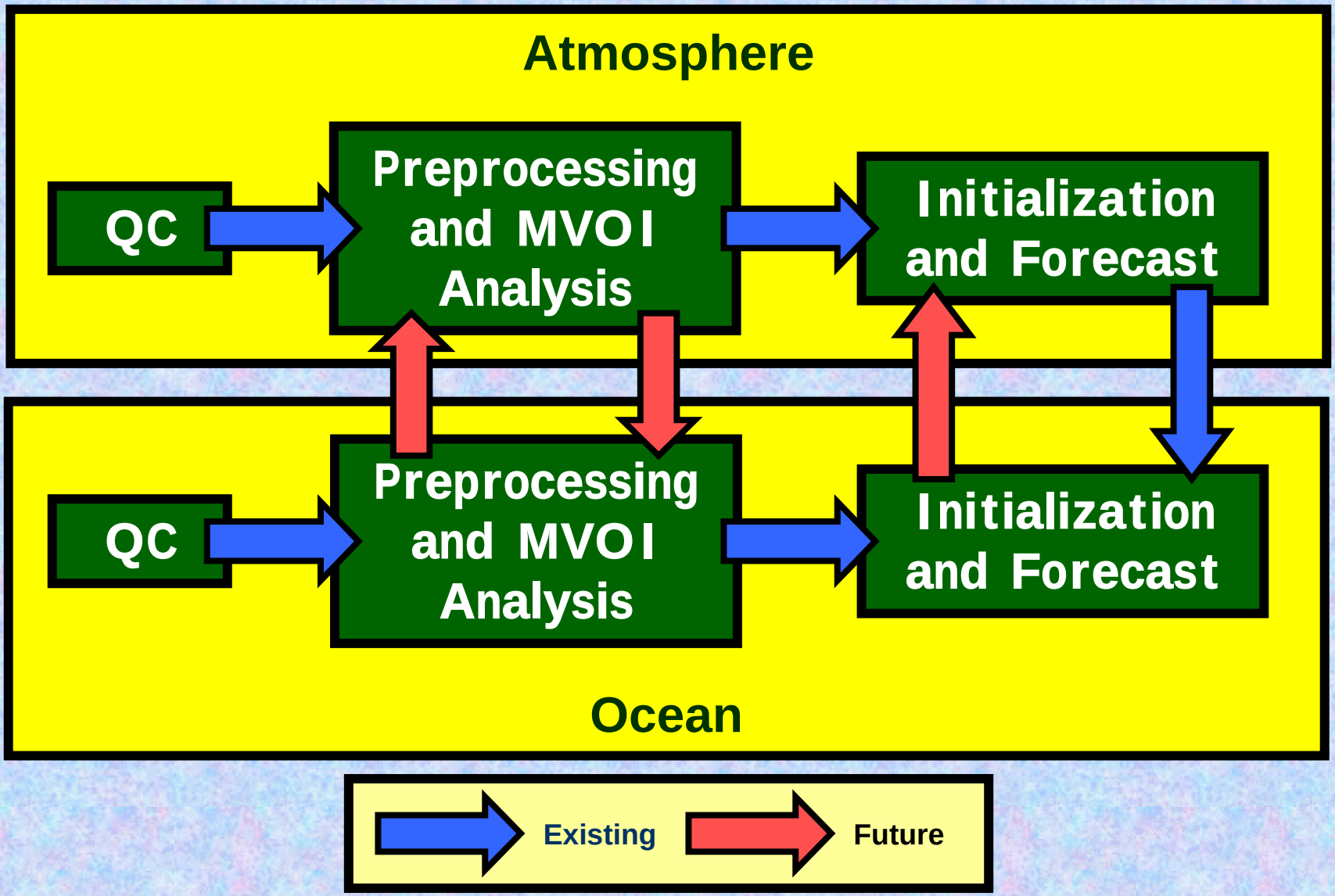
Approach

Coupled Mesoscale Modeling of the Atmosphere and Ocean

- **Utilize existing mesoscale atmosphere and ocean data assimilation systems:**
  - Atmospheric data assimilation system in the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™)
  - 3-dimensional ocean multivariate optimum interpolation analysis (3D MVOI)
  - NRL Coastal Ocean Model (NCOM)
- **Initial tests of the coupled system will focus on the Mediterranean Sea**

COAMPS™

Coupled Ocean/Atmosphere Mesoscale Prediction System



COAMPS™

Coupled Ocean/Atmosphere Mesoscale Prediction System: **Atmospheric Components**

- **Complex Data Quality Control**
- **Analysis:**
  - Multivariate Optimum Interpolation Analysis (MVOI) of Winds and Heights
  - Univariate Analyses of Temperature and Moisture
- **Initialization:**
  - Variational Hydrostatic Constraint on Analysis Increments
  - Digital Filter
- **Atmospheric Model:**
  - Numerics: Nonhydrostatic, Scheme C, Nested Grids, Sigma-z, Flexible Lateral BCs
  - Physics: PBL, Convection, Explicit Moist Physics, Radiation, Surface Layer
- **Features:**
  - Globally Relocatable (5 Map Projections)
  - User-Defined Grid Resolutions, Dimensions, and Number of Nested Grids
  - 6 or 12 Hour Incremental Data Assimilation Cycle
  - Can be Used for Idealized or Real-Time Applications
  - Single Configuration Managed System for All Applications
  - Operational at FNMOC:
    - 8 Areas, Twice Daily, using 81/27/9 km or 81/27 km grids
    - Forecasts to 72 hours
  - Operational at all Navy Regional Centers (w/GUI Interface)

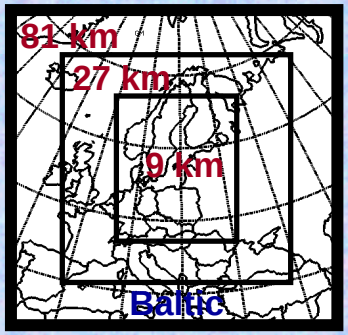
COAMPS™

Coupled Ocean/Atmosphere Mesoscale Prediction System: **Ocean Components**

- **Data Quality Control**
- **Analysis:**
  - 2D Multivariate Optimum Interpolation Analysis (MVOI) of Sea Surface Temperature on All Grids
  - 3D MVOI Analysis of Temperature, Salinity, Surface Height, Sea Ice, and Currents
- **Ocean Model: Navy Coastal Ocean Model (NCOM)**
  - Numerics: Hydrostatic, Scheme C, Nested Grids, Hybrid Sigma/z
  - Parameterizations: Mellor-Yamada 2.5
- **Features:**
  - Globally Relocatable (5 Map Projections)
  - User-Defined Grid Resolutions, Dimensions
  - Can be Used for Idealized or Real-Time Applications
  - Single Configuration Managed System for All Applications
  - Loosely coupled to COAMPS atmospheric model

Atmospheric Reanalyses

Purpose: Generate high-resolution fields for forcing an ocean model



- Cold start at first analysis time
- 12 hour incremental data assimilation cycle
- Hourly output from forecast model
- SST analysis every 12 hours for each grid
- Four areas:
  - Mediterranean (81/27 km)
  - Eastern Pacific (81/27/9 km)
  - Adriatic (36/12/4 km)
  - Baltic Sea (81/27/9 km)

NOGAPS Fields

Observations → Analysis

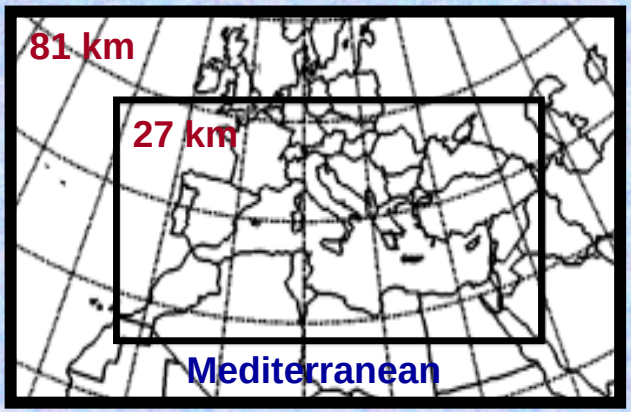
24 h Forecast

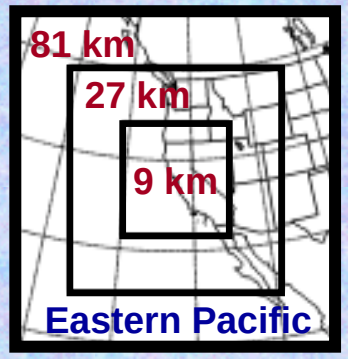
Observations → Analysis

24 h Forecast

Observations → Analysis

24 h Forecast





Atmospheric Reanalyses

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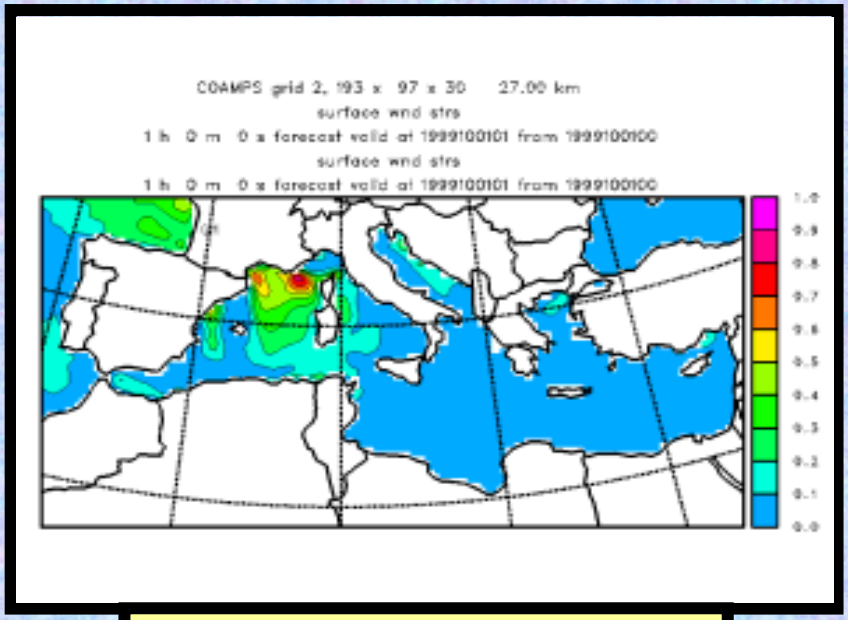
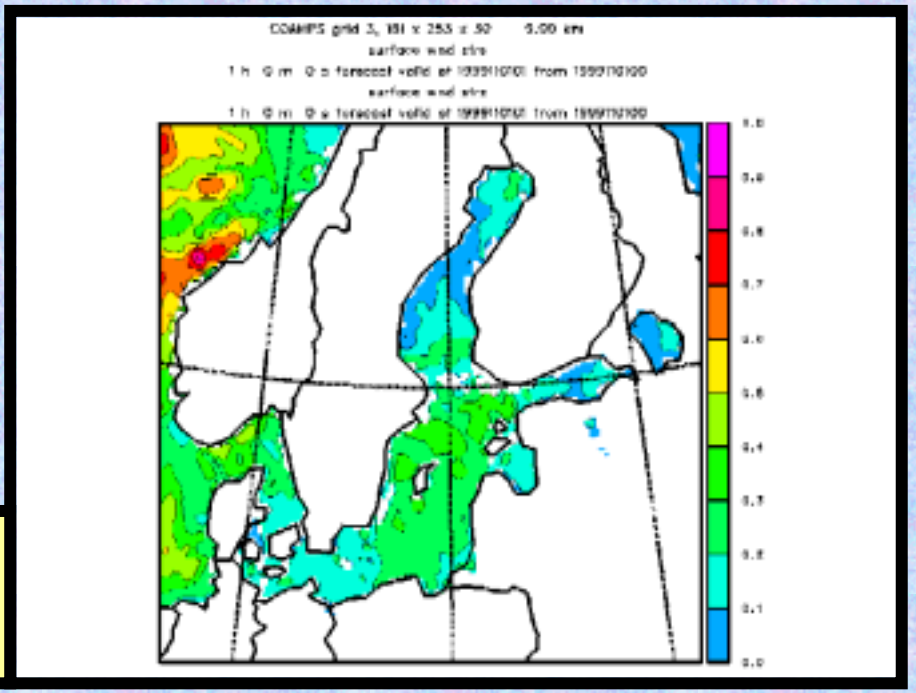


Surface Wind Stress (N/m^2)
Mediterranean 27 km Grid
October 1999

Current Status:

- **Mediterranean (27 km): Oct 98 - Mar 01**
- **Eastern Pacific (9 km): Oct 98 - Sep 00**
- **Baltic Sea (9 km): Nov 99 - Feb 00**
- **Adriatic Sea (4 km): Nov 99 - Aug 01**



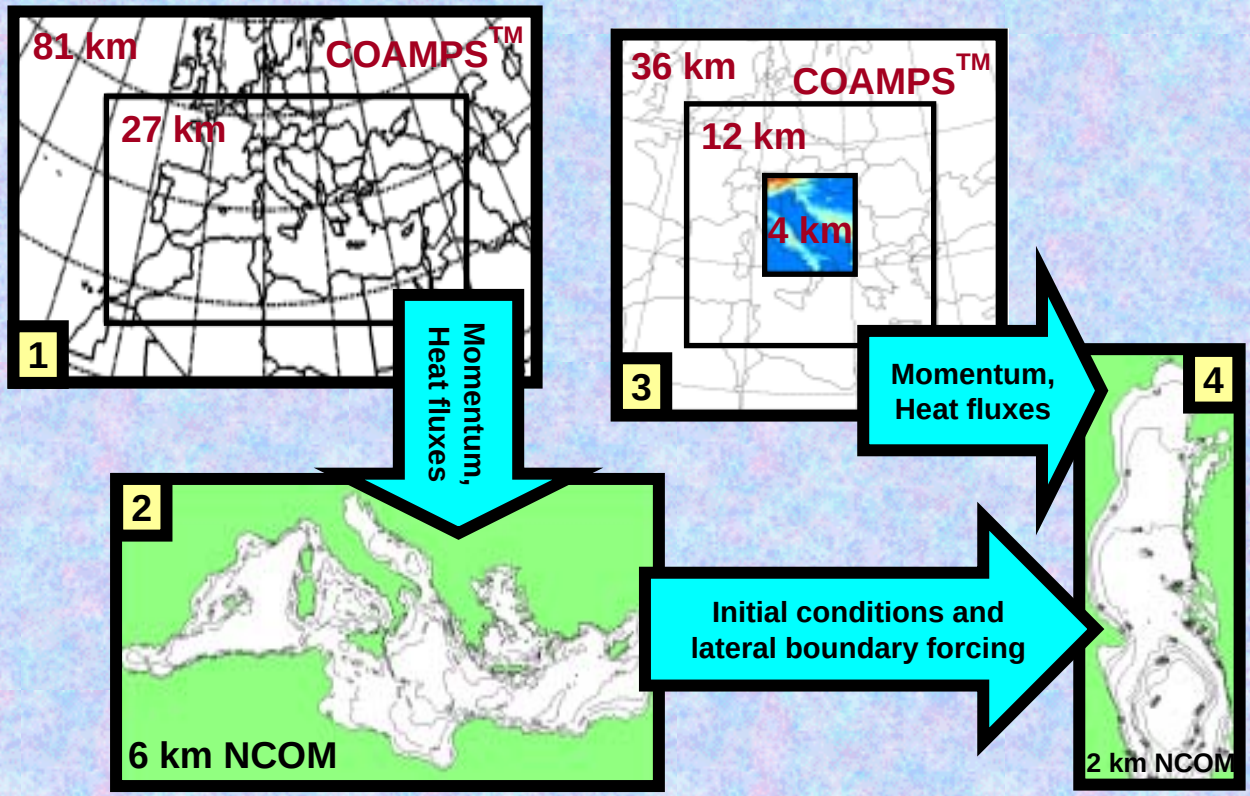
Surface Wind Stress (N/m^2)
Baltic Sea 9 km Grid
November 1999

Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

Objectives

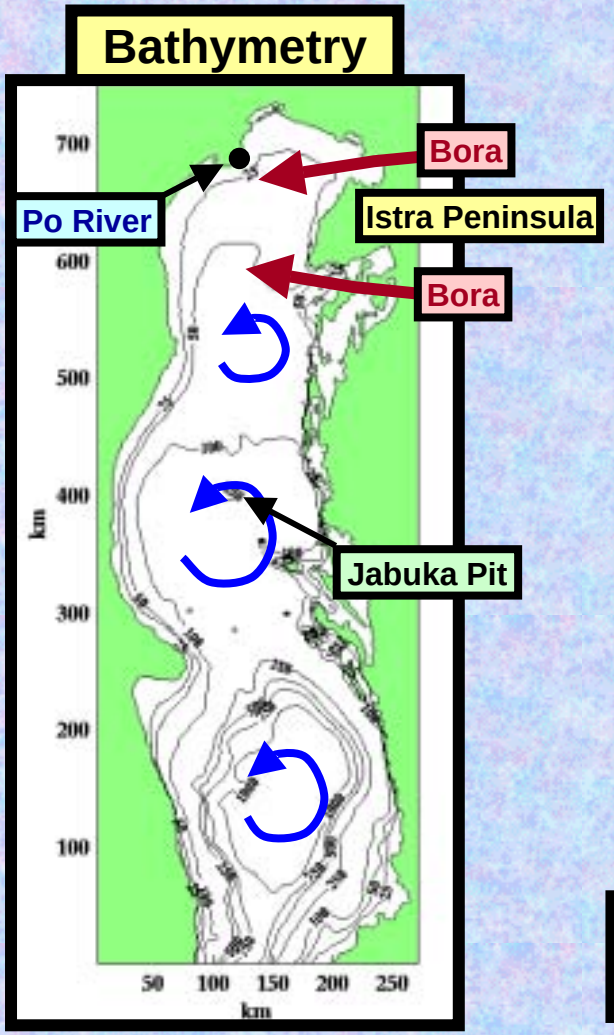
- Simulate Adriatic atmospheric and oceanic circulation at high resolution
- Document and understand response of the shallow northern Adriatic waters to forcing by the Bora and Po river run-off
- Quantify the effects of coupling (e.g., one-way, two-way, frequency, resolution) on atmosphere and ocean forecasts
- Aid in planning and interpreting Adriatic Circulation Experiment (ACE) observations

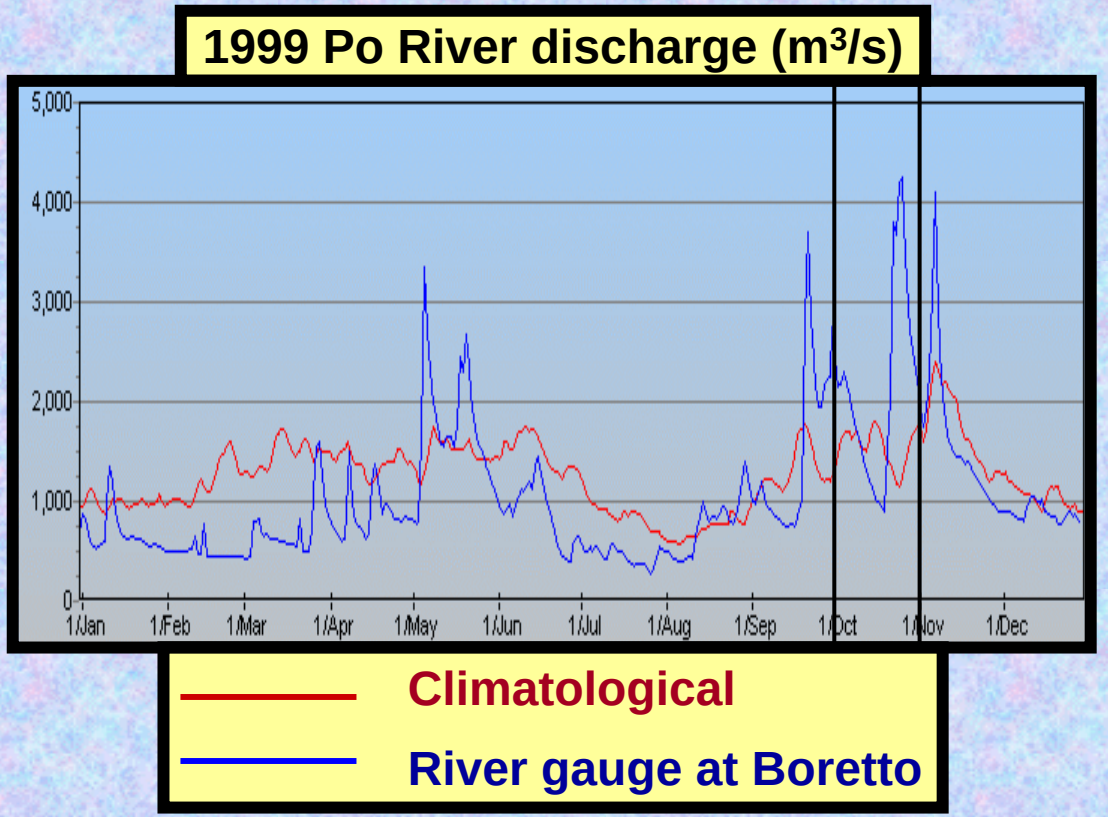
1. Generate 27 km atmospheric forcing fields over the Med
2. Generate 6 km, 2-year spin-up of the Med using forcing from #1, then 12-hour data assimilation for October 1999
3. Generate 4 km atmospheric forcing fields over the Adriatic Sea
4. Generate 2 km Adriatic forecasts using initial conditions and inflow from #2, and atmospheric forcing from #3



Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

Adriatic Circulation and Forcing





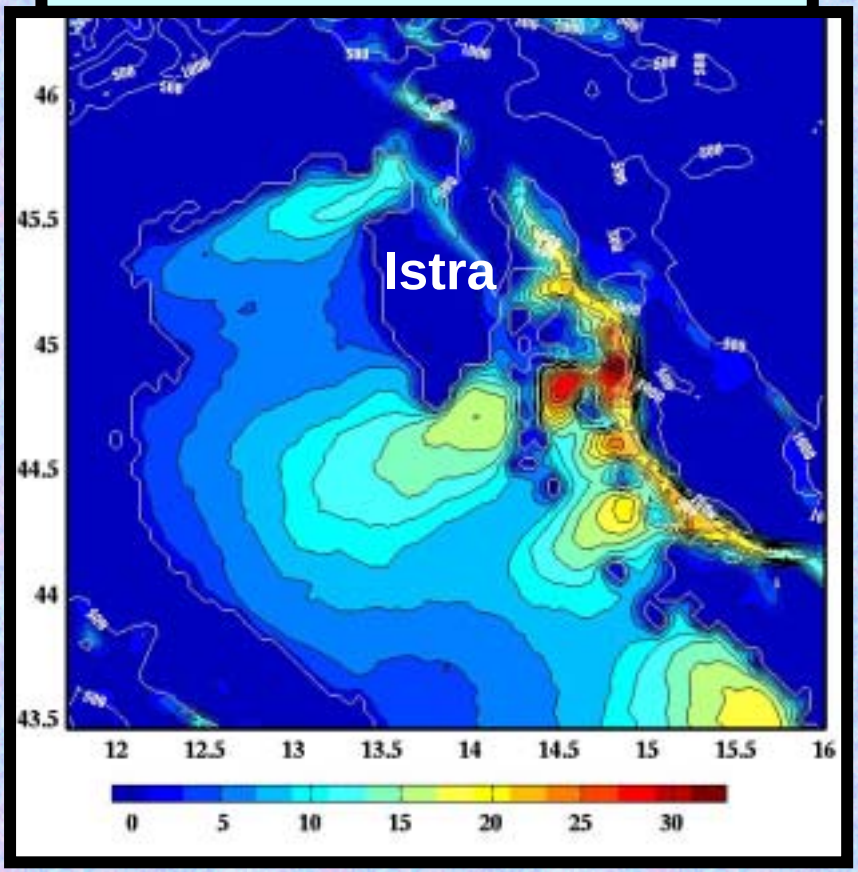
River data from Servizio Idrografico e Mareografico Nazionale (SIMN), Italy acquired by Rich Signell

Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

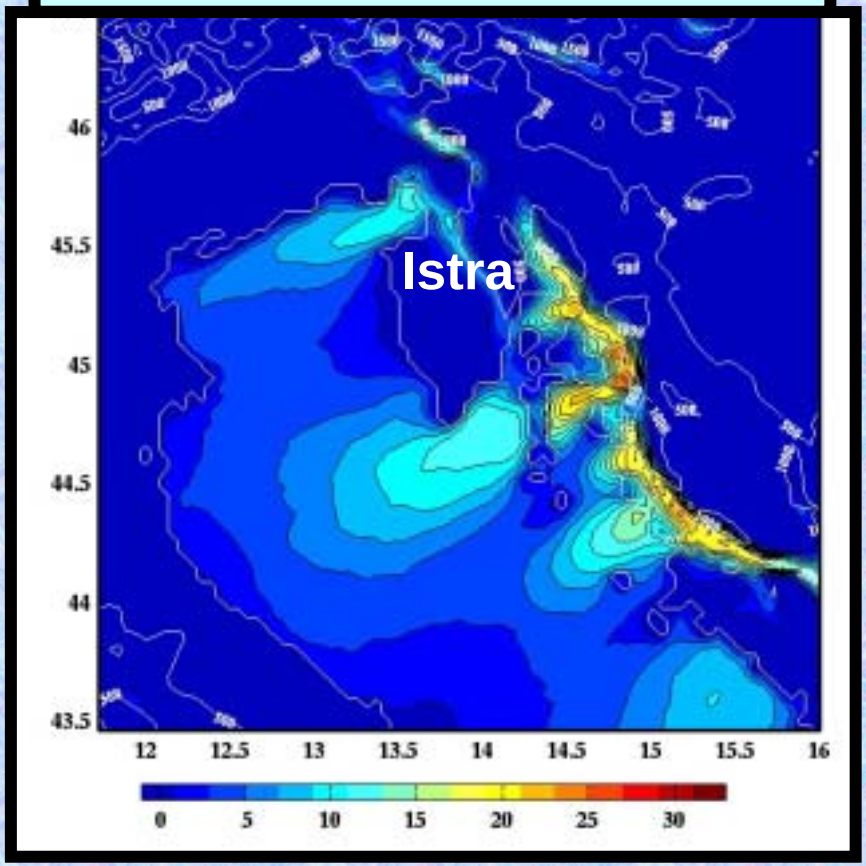
Climatological Frequency of Boras

Based on Hourly COAMPS™ 10 m winds from 15 Jan - 1 June 2001 Reanalyses

% of Time that Wind Speed is Greater than 10 m s^{-1}



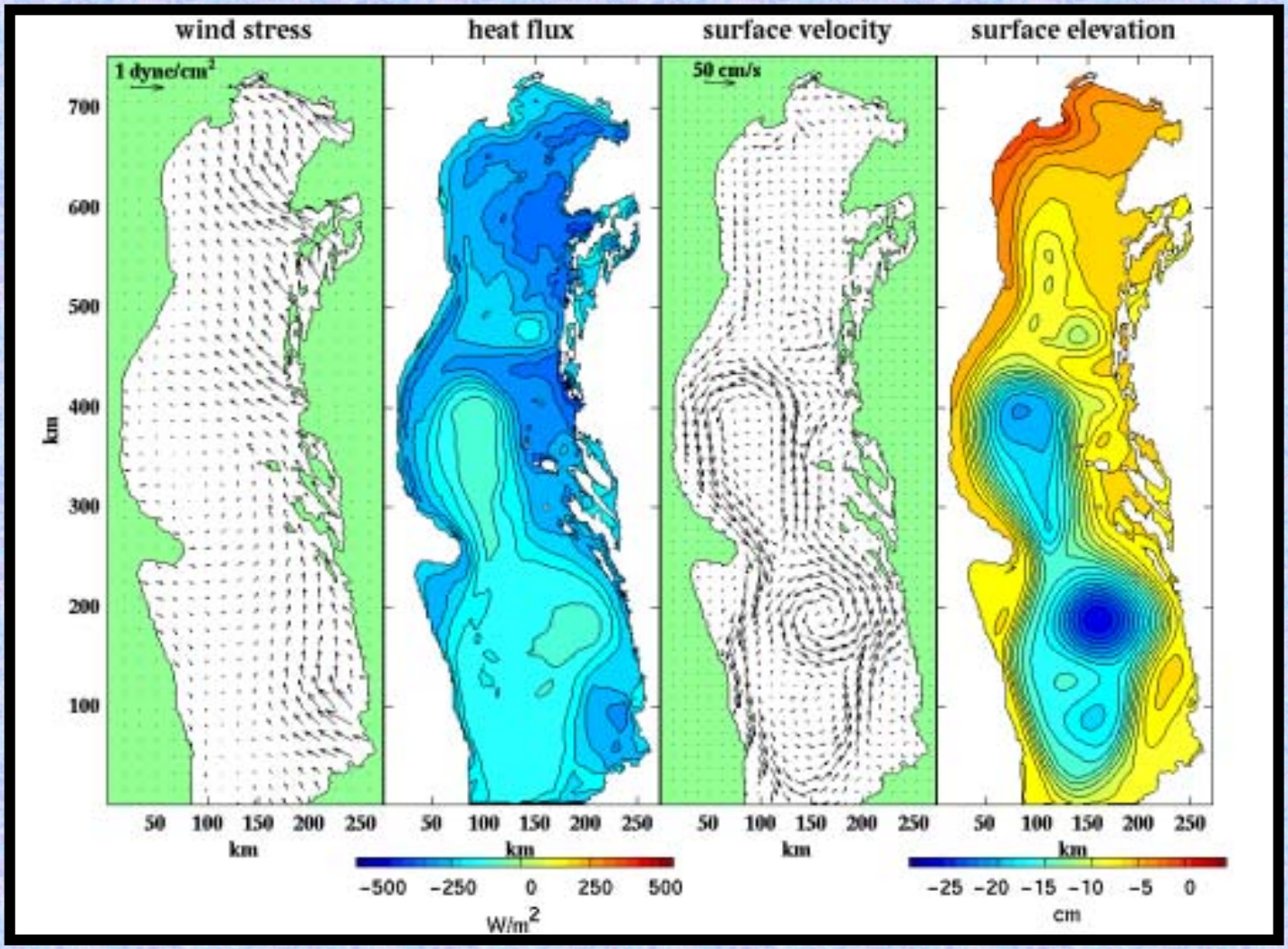
% of Time that Wind Speed is Greater than 10 m s^{-1} and Wind Direction is Northeast



Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

October 1999: Mean Fields

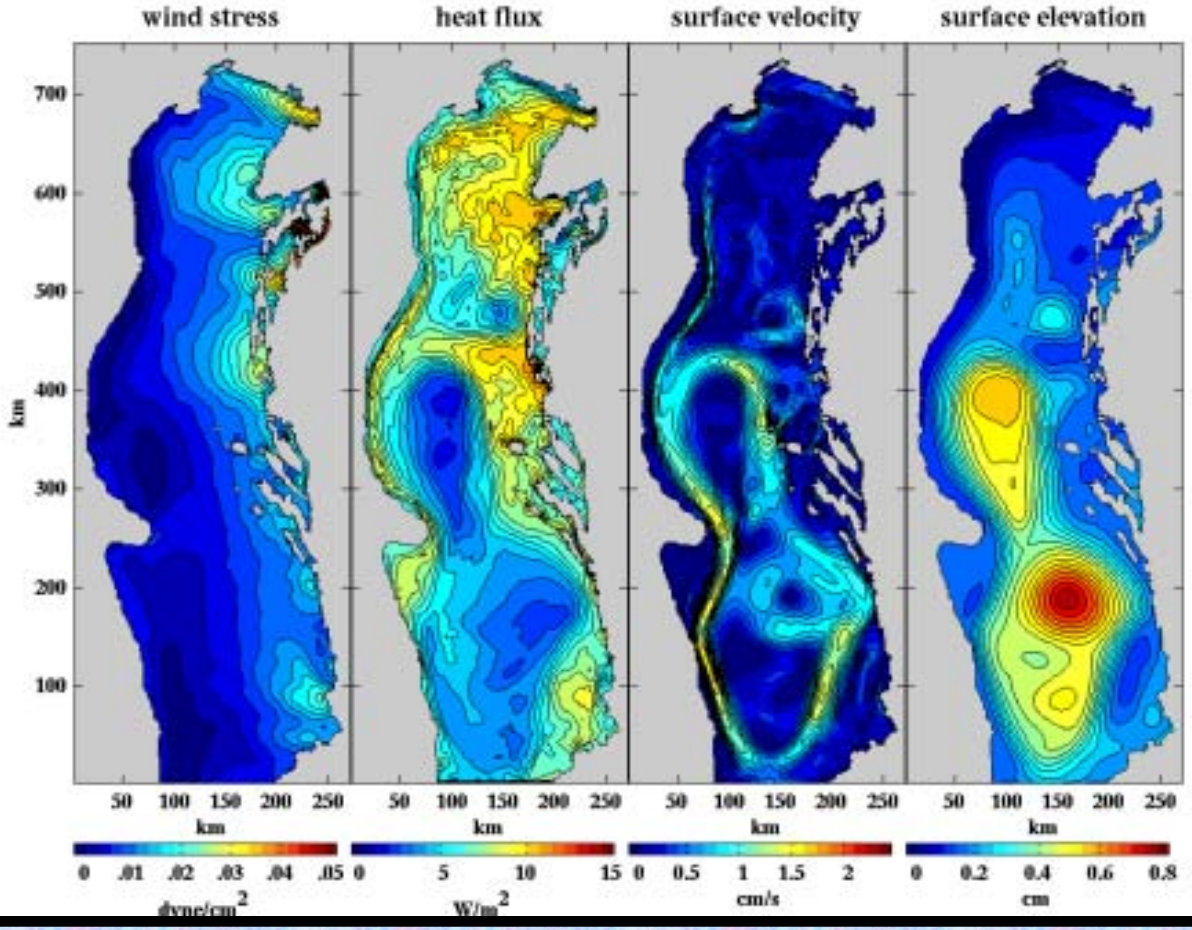
4 km COAMPS™ atmospheric grid; 2 km NCOM ocean model grid



Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

October 1999: Standard Deviation

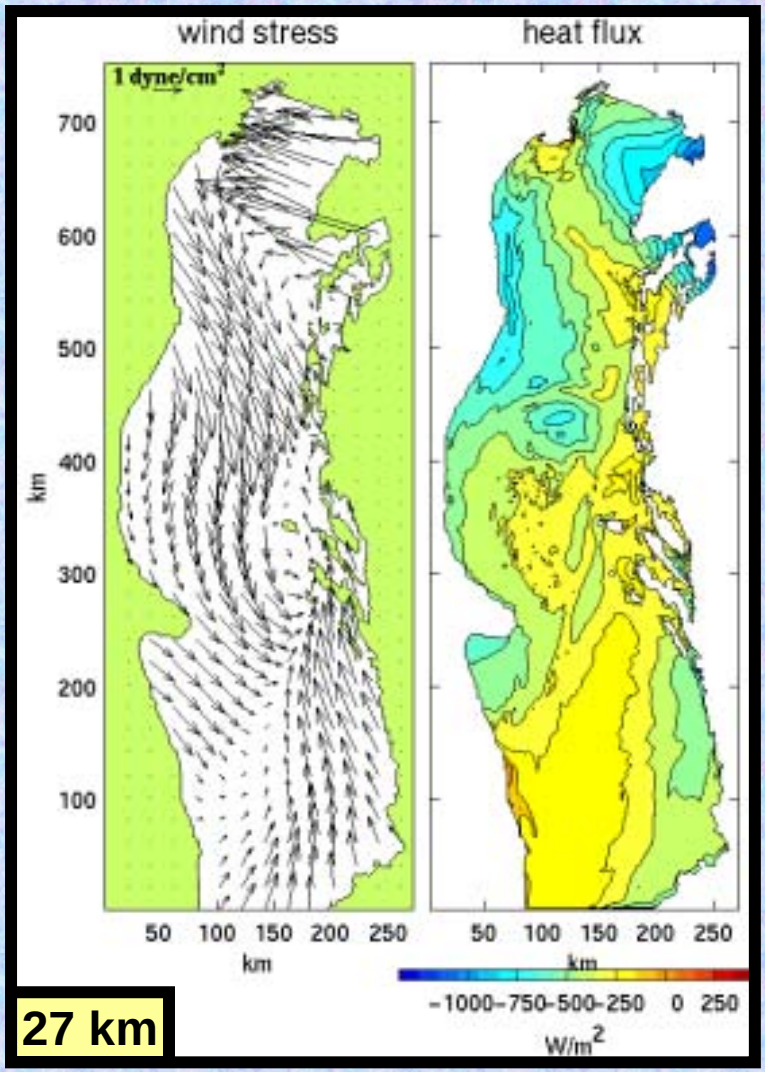
4 km COAMPS™ atmospheric grid; 2 km NCOM ocean model grid

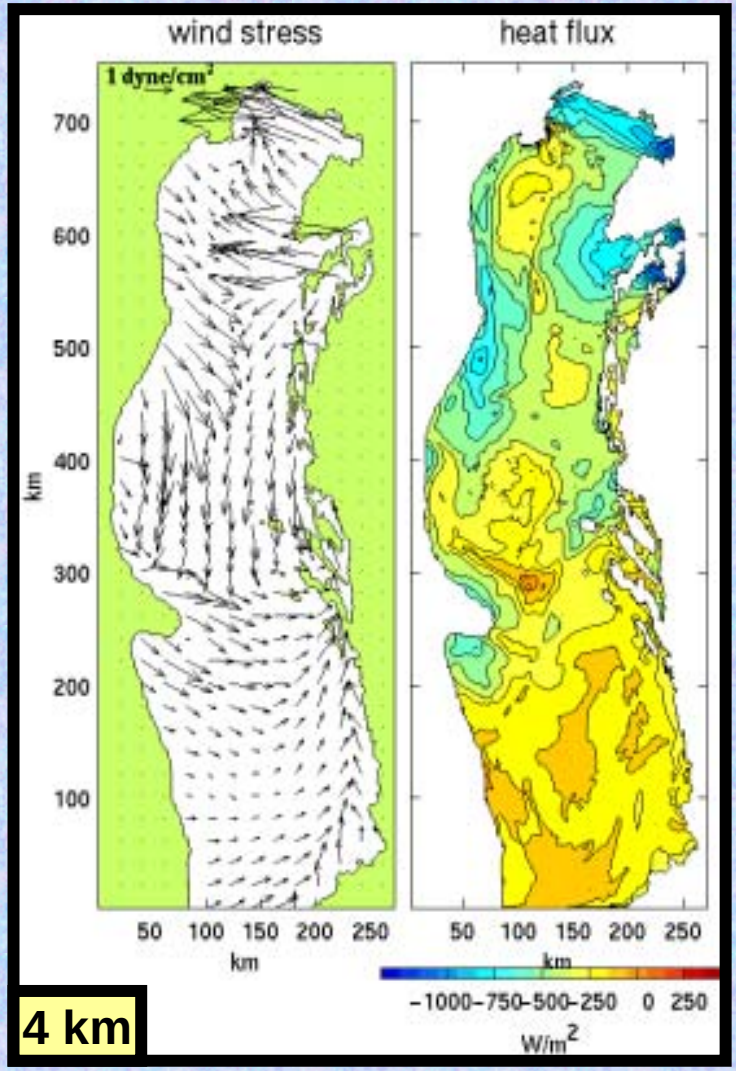


Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

COAMPS™ Fields: 5 October 1999

Resolution Comparison: Atmospheric Forcing

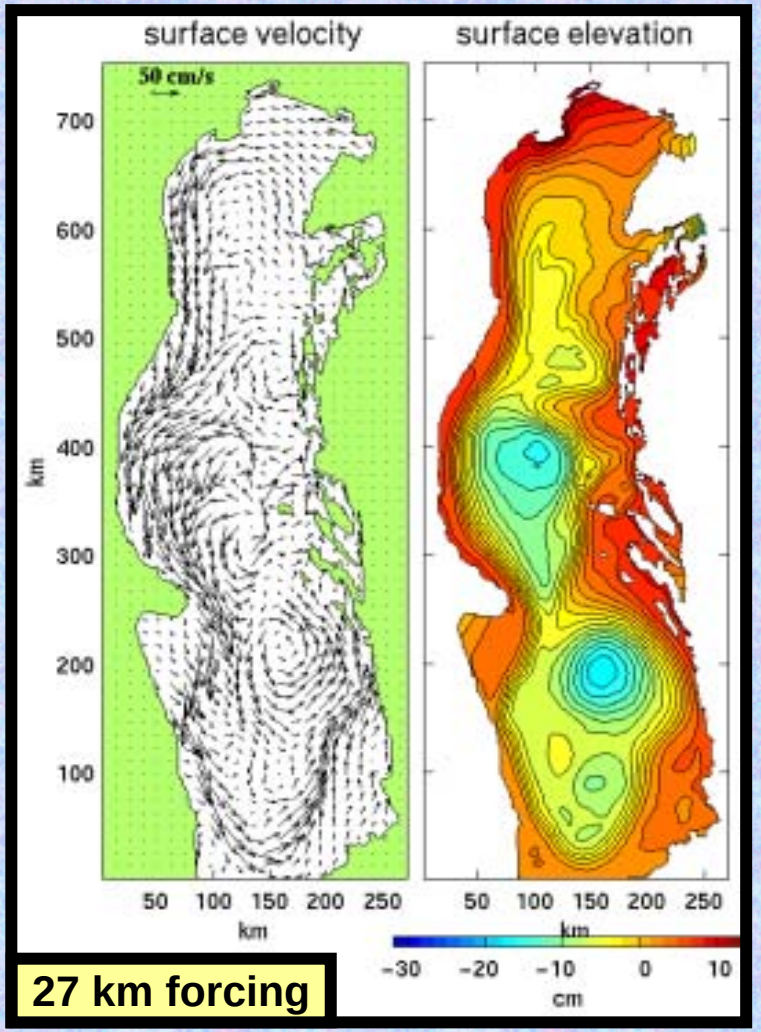




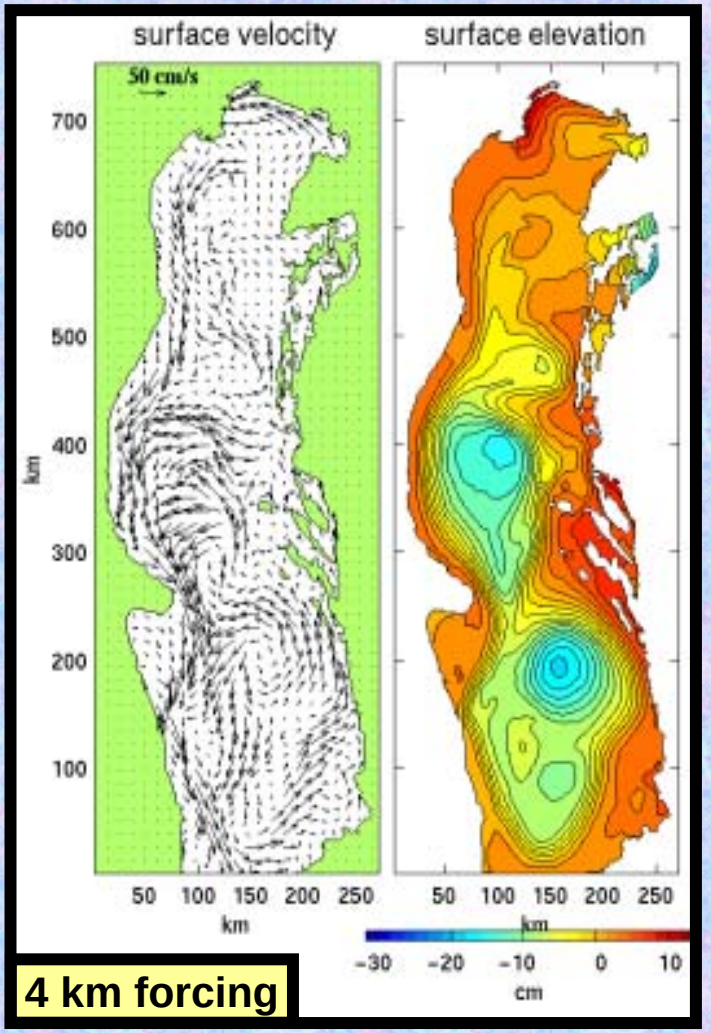
Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

2 km NCOM Fields: 5 October 1999

Comparison of Ocean Model Results Using Atmospheric Fields with Different Resolutions



27 km forcing

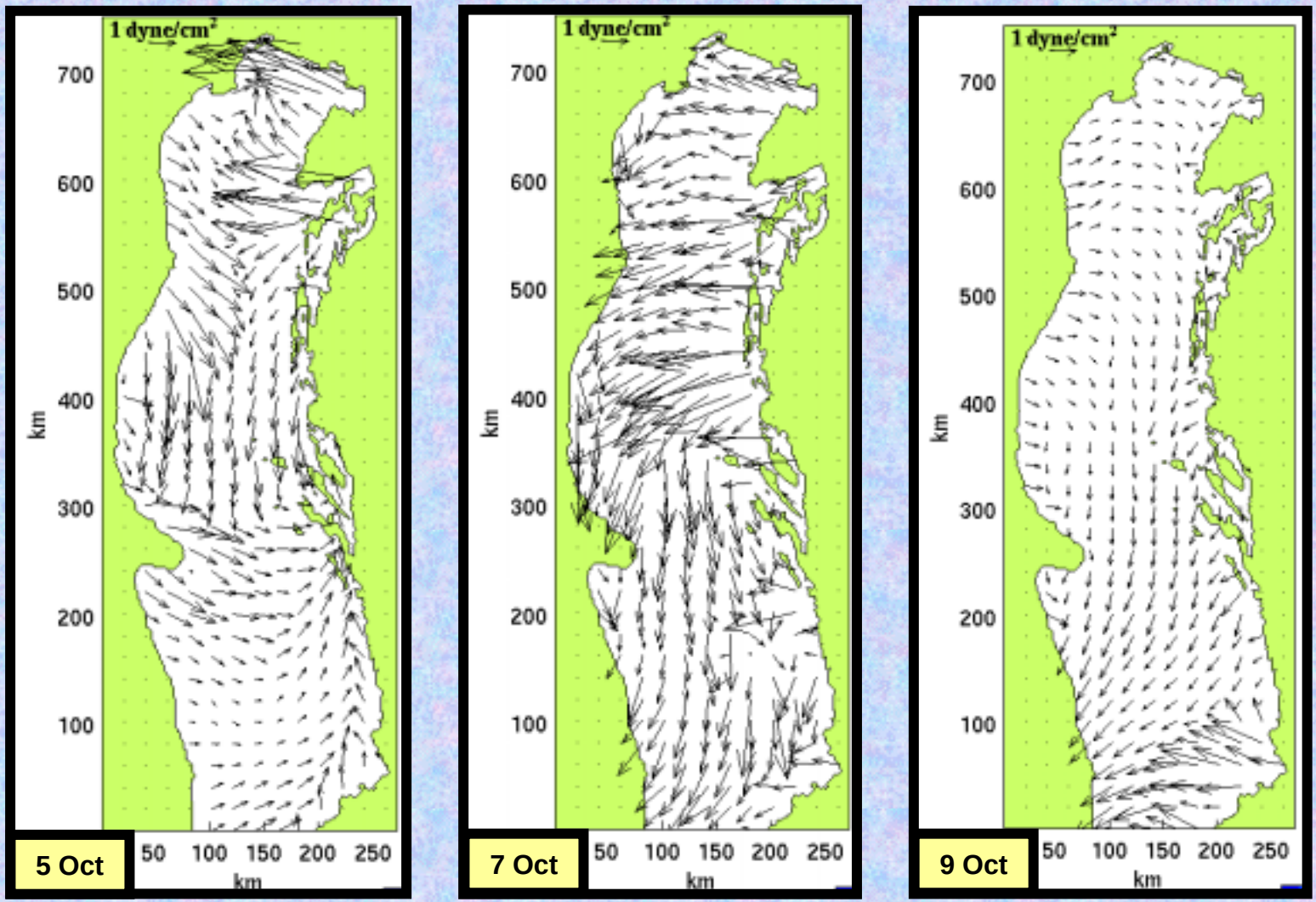


4 km forcing

Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

Effect on Po River Discharge

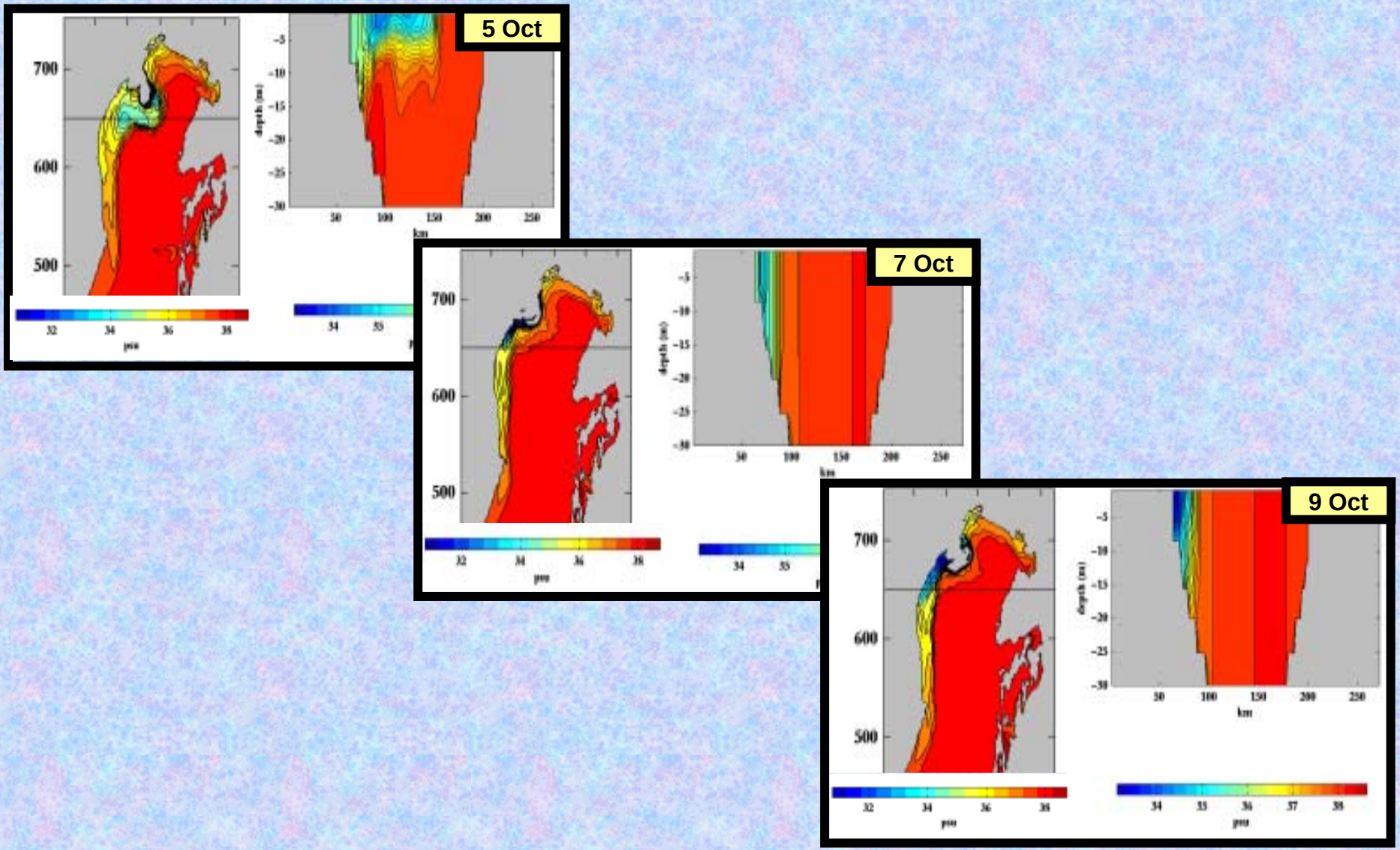
COAMPS™ wind stress: 5, 7, and 9 October 1999



Coupled Air-Ocean Nested Modeling Studies of the Adriatic Sea

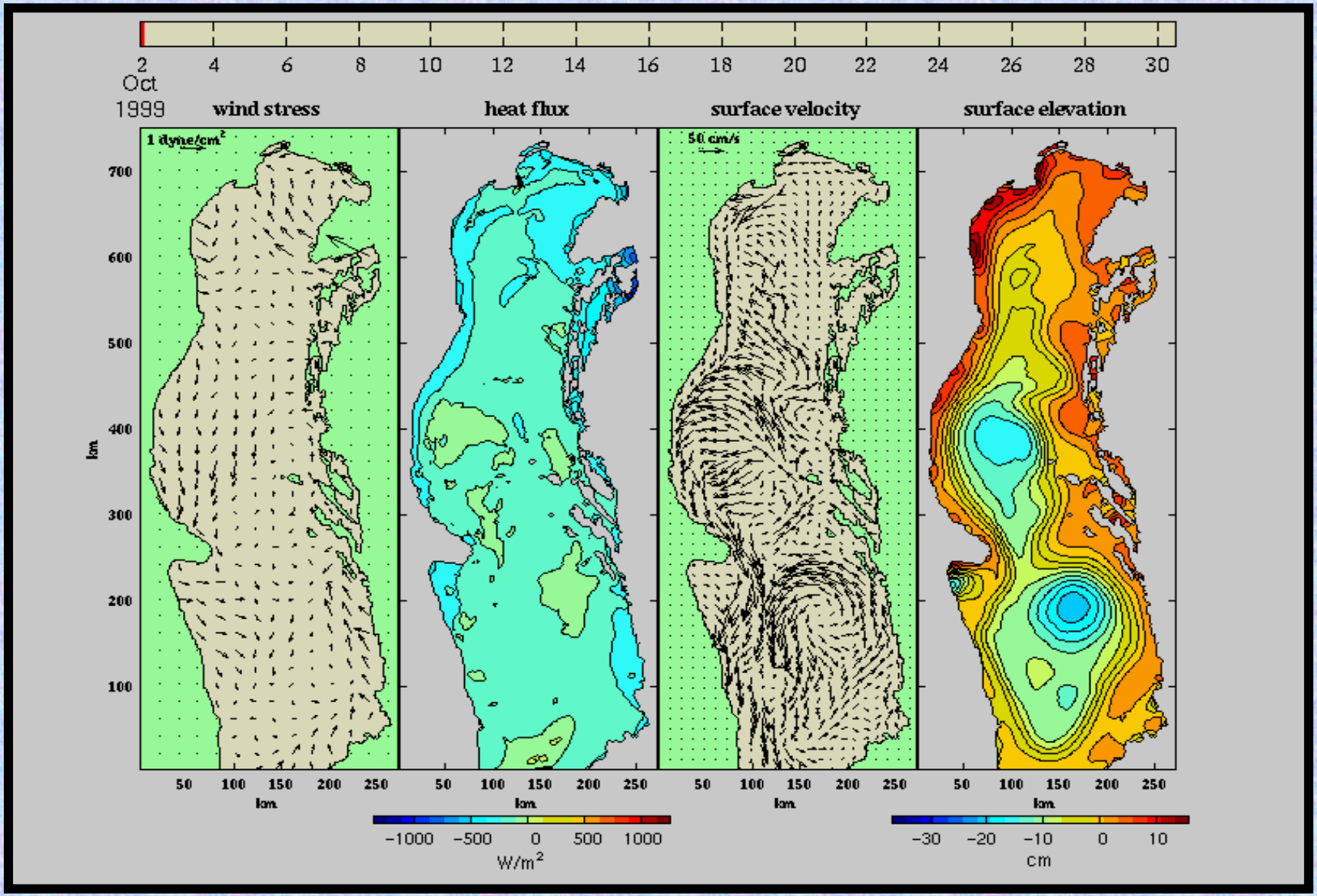
Effect on Po River Discharge

NCOM salinity: 5, 7, and 9 October 1999

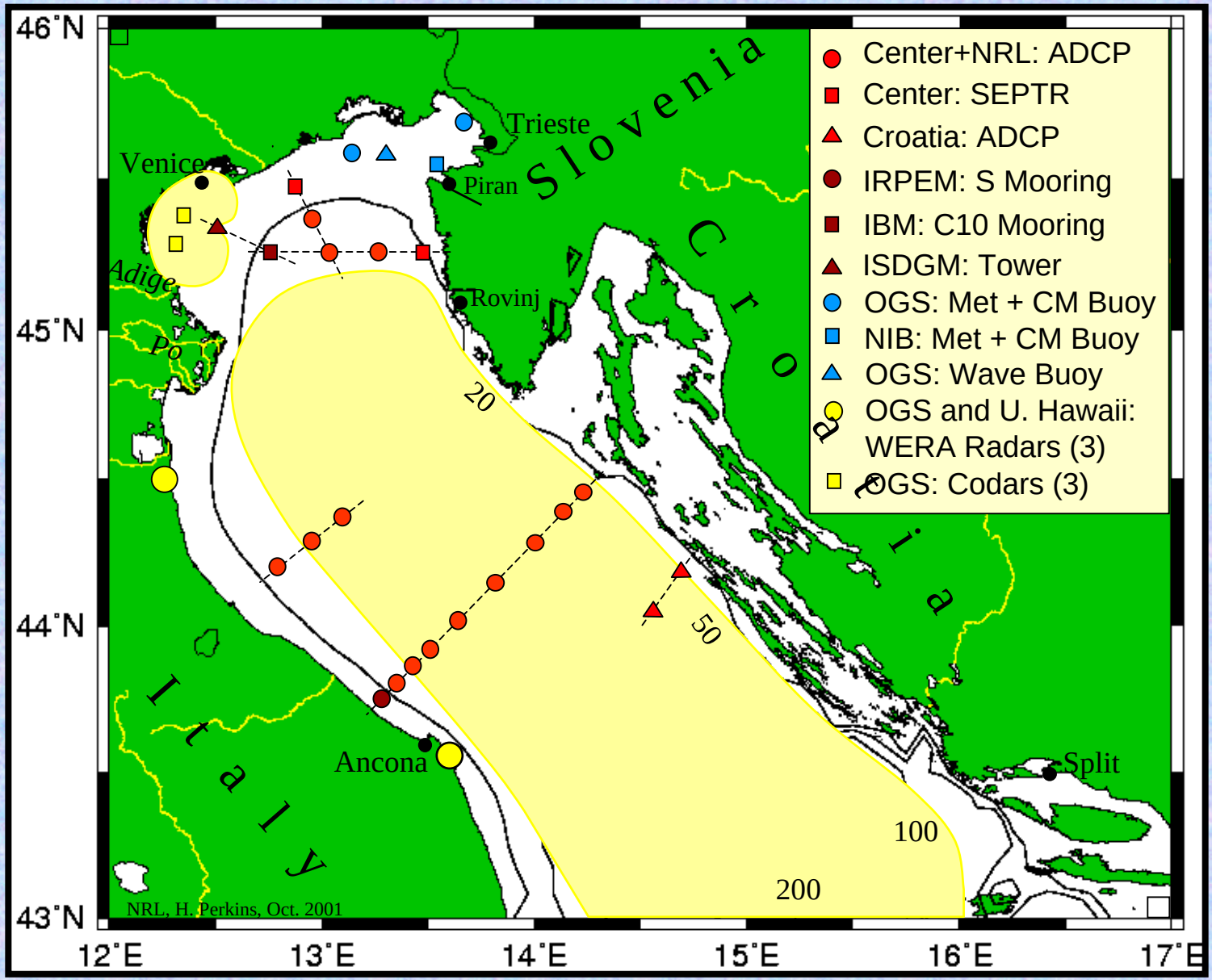


Nested Modeling Studies of the Adriatic Sea

Animation of 2 km Adriatic NCOM Simulation for Oct 1999

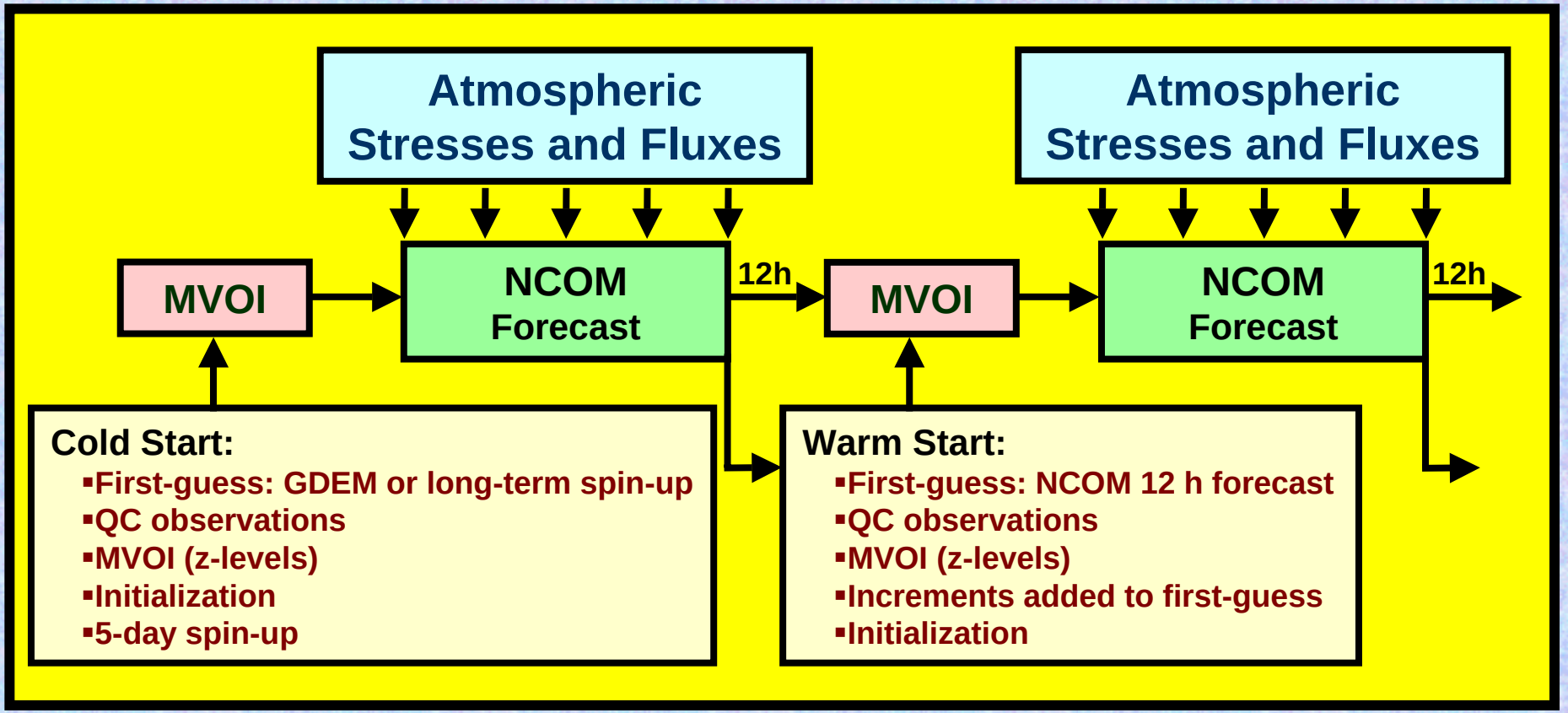


ACE Measurements at Fixed Sites: Winter 2002-2003 (Hank Perkins, NRL-SSC)



Data Assimilation

Data Assimilation: MVOI-NCOM Interface

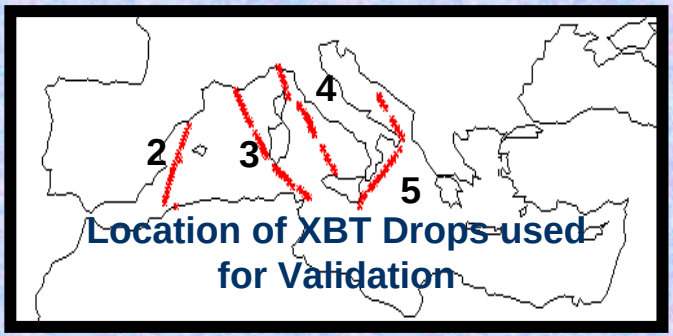


Data Assimilation Validation

October 1999

DETAILS OF EXPERIMENTS

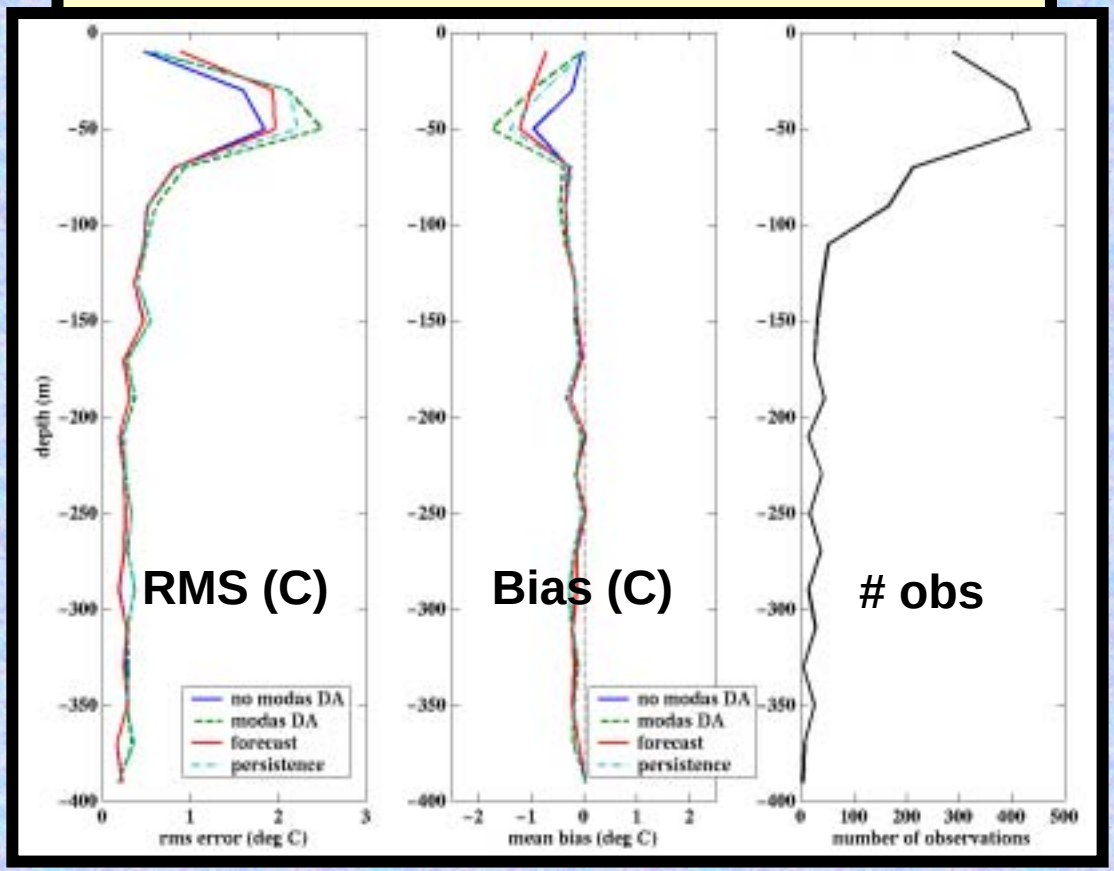
- NCOM: 6 km/40L
- Cold Start on 1 October 1999
- 12 h incremental data assimilation



Location of XBT Drops used for Validation

MFSPP: Mediterranean Forecast System Pilot Project, POCs: Nadia Pinardi and Giuseppe Manzella

Validation with MFSPP XBT Observations

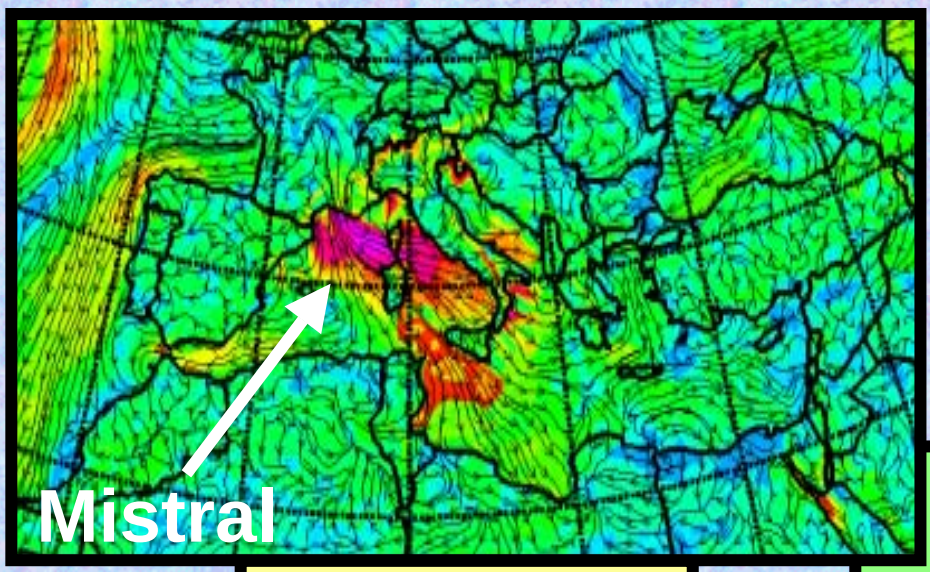


Temporal Variations of the Ocean Mixed-Layer in the Mediterranean

- **Objective:** Study the effect of strong ocean forcing due to the Mistral on the ocean mixed-layer
- **Approach:**
  - Run 10-year NCOM spin-up using climatological winds
  - Extend spin-up for 2 years using forcing from the COAMPS™ 27 km reanalysis
  - Evaluate ocean model response during Mistral events
- **NCOM Setup:**
  - 6 km grid spacing
  - 40 levels, 15 sigma
  - Mellor-Yamada 2.0

Temporal Variations of the Ocean Mixed-Layer in the Mediterranean

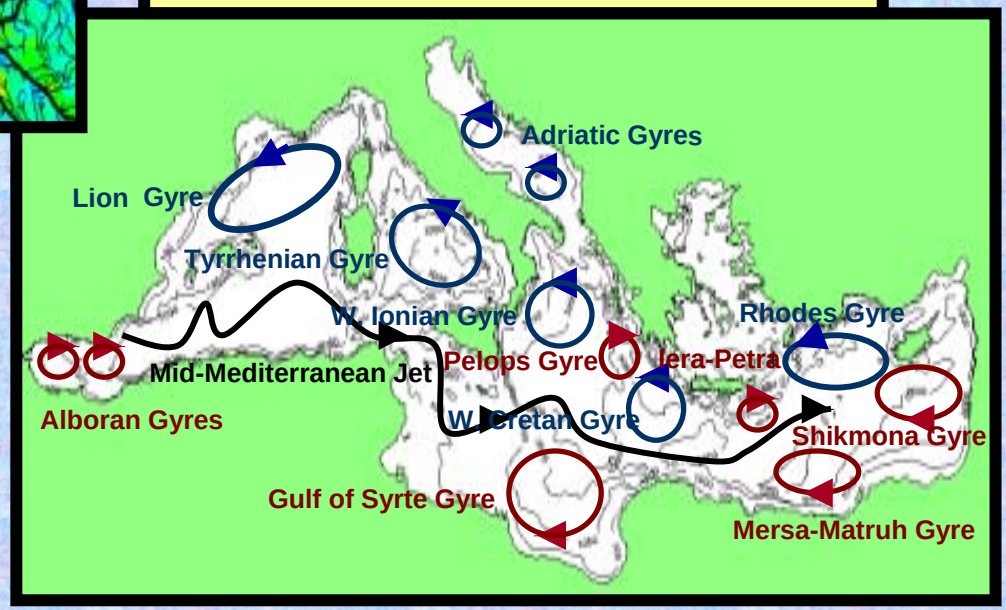
Examples of the Mistral and the Circulation of the Mediterranean



Circulation of the Mediterranean

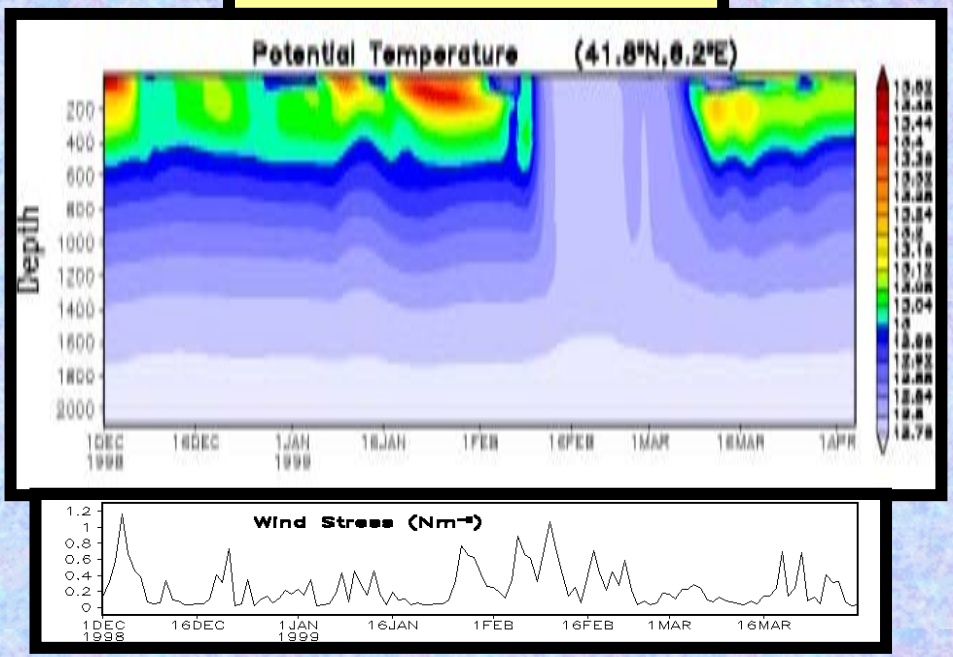
Cyclonic Gyre

Anticyclonic Gyre



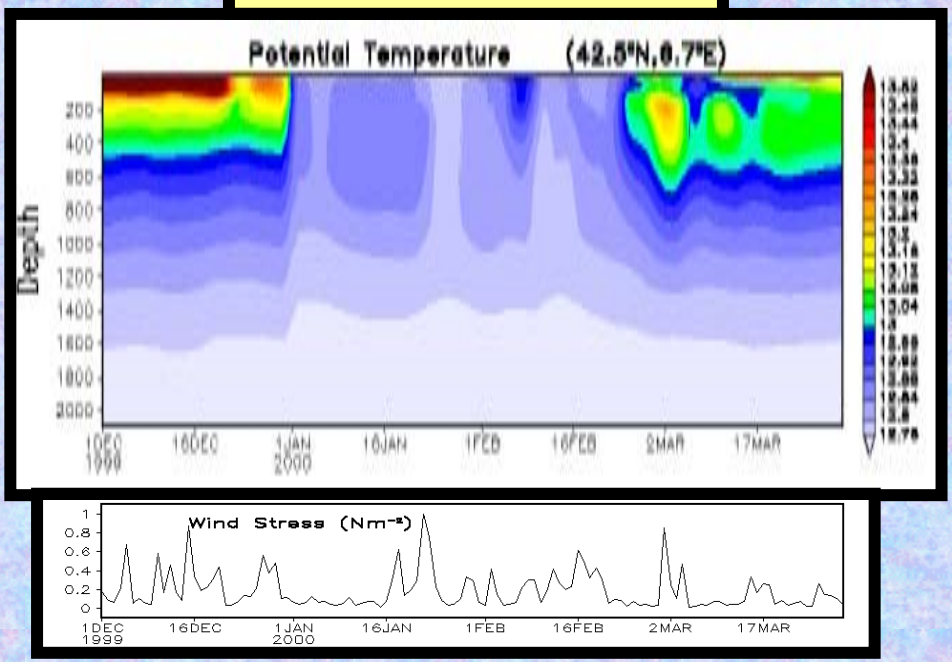
Time-Series of Ocean Mixed-layer Response to Strong Surface Cooling and Mixing

1 Dec 98 - 1 Apr 99



- Strong Mistral events erode surface stratification
- Mixing interrupted with warm surface water recapping
- Strongest cooling event occurred on 11 Feb 1999, with mixing to 1800 m depth
- Well-mixed column of water maintained for about 20 days by subsequent Mistral events
- The Levantine Intermediate Water (LIW) advected into the area in Mid-March

1 Dec 99 - 1 Apr 00



- Surface layer stratification eroded by the end of Dec 99
- Deepest mixing reached 1400 m following Mistral event on 23 Jan 2000
- The vertically well-mixed column of water was restratified in a few days
- Levantine Intermediate Water back in early Mar 00

Coupled Mesoscale Modeling of the Atmosphere and Ocean

Summary

- **COAMPS™ Reanalyses**
  - On-going, high-resolution reanalyses for 4 areas
  - Using unfiltered, native-grid fields for coupling
- **Nested Modeling Studies of the Adriatic Sea**
  - Investigated coastal Adriatic response to Bora winds and Po river discharge
  - Examined Adriatic as test bed for ocean/atmosphere coupling strategies
  - Validated model/Evaluated data assimilation in coastal areas using ACE observations
- **Ocean Data Assimilation**
  - Testing 12 hour incremental data assimilation cycle
  - Assessing methods for assimilating data
- **Temporal Variations of the Ocean Mixed-Layer in the Mediterranean**
  - Examined role of Mistral in mixed-layer formation
  - Documented annual variations in mixed-layer